THIS IS AN ORIGINAL MANUSCRIPT
IT MAY NOT BE COPIED WITHOUT
THE AUTHOR'S PERMISSION

GEOLOGY OF SAUDI ARABIA

Approved:

Hal P. Bybee

F. H. Lahee

Don L. Frizzell

Approved:

A. P. Brogan
Dean of the Graduate School

GEOLOGY OF SAUDI ARABIA

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas in Partial Fulfillment

of the Requirements

For the Degree of

MASTER OF ARTS

By

Abdulla Homoud Tariki, B.S.

Austin, Texas

August, 1947

THE LIBRARY
THE UNIVERSITY
OF TEXAS

TABLE OF CONTENTS

AUTHOR GIFT
NOV 29 1947
566624

TABLE OF CONTENTS, CONTINUED

TABLE OF CONTENTS, CONTINUED

ILLUSTRATIONS

THE LIBRARY
THE UNIVERSITY
OF TEXAS

ABSTRACT

Saudi Arabia is readily divisible into two geological provinces.

The western area consists of crystalline igneous and metamorphic rocks, of presumed Pre-Cambrian age, topographically and structurally sloping to the northeast, east and southeast.

The eastern area has easterly dipping sedimentary rocks overlying the basal igneous and metamorphic complex. These sediments consist of Paleozoic, Mesozoic (nearly complete section), Tertiary, and Recent deposits. The area is subdivided into Nejd and Hassa (Persian Gulf) subprovinces.

The eastern parts of Nejd subprovince consist of sedimentary rocks, ranging in age from early Paleozoic to early Eocene. These sediments consist of alternating calcareous and clastic facies. Differences in the relative resistance of these rocks are responsible for smooth, gently dipping slopes to the east, on the one hand, and truncated west-facing escarpments on the other. Examples of these resistant rocks are found in the Jurassic strata of the Tuwaiq Mountains which extend in a north-south direction. Another example is the Aruma Plateau, capped by resistant limestone of Upper Cretaceous age. There is an absence of marked altitudinal variations in the Nejd sedimentary rocks, and, hence, the rather uniform homoclinal dip has been preserved.

In the Hassa subprovince the outcropping rocks are limited to the Tertiary and later; these include the lower and middle Eocene, and Miocene to Pliocene. The Eocene rocks are almost entirely calcareous, except one local anhydrite member on the coast of the Persian Gulf. The Miocene and Pliocene strata are primarily continental deposits, except

for some intercalated marine beds. The latter are composed of marls, clays, sands, and thin limestone, and they cover the Eocene sediments in most of the Hassa Province.

INTRODUCTION

The Department of Geology of the University of Texas suggested the research problem which is the subject of this paper. Little information dealing directly with the area in question has been found in the few available sources.

The writer communicated with Mr. James Terry Duce, Vice-President of the Arabian American Oil Company, Washington, D. C., who kindly furnished company reports and maps which have served as the chief sources of information.

Consistency in using only one unit of measurement was not possible since the sources of information included both metric and English units. To insure as much accuracy as possible the author felt it best to leave the units as stated in the sources.

The writer regrets that he is unable to give a detailed description of the geology of Saudi Arabia; this part of the world has not been studied to any great extent. However, he has attempted to give as detailed a survey of the geology, structure and oil reservoirs of the region as available sources of information will permit.

LOCATION AND GENERAL FEATURES OF SAUDI ARABIA

Saudi Arabia occupies most of the Arabian Peninsula. It has an area of about 865,000 square miles. Saudi Arabia is bordered by the Red Sea on the west, Trans-Jordan and Iraq on the north, Kuwait Principality, Persian Gulf and Qatar Peninsula on the east, and on the south by Yemen Kingdom, Hadhramaut, and Oman Provinces.

Saudi Arabia consists of five provinces. These are: Hejaz where Mecca and Medina, the Moslem's Holy Cities are located; Assir, south of Hejaz, a raised plateau concerning which little geological information is available; Nejd, the center of Arabia, a high, sandy plateau where most of the Arabian tribes live; and Hassa or Persian Gulf Province which has become the most important part of Saudi Arabia because of the discoveries of the huge oil reservoirs under its soil.

Saudi Arabia generally is barren, a large portion being covered by sand dunes and rocky regolith. The "backbone" of the Arabian Peninsula is the Tuwaiq Mountain chain, extending, in general, in a north-south direction. The sand dunes of Dahna roughly parallel the mountains, and there culminate in the great field of sand dunes of the north and south, known as Great Nufud and Rub Al Khali, respectively.

Saudi Arabia is about seven hundred miles wide, measured from the Persian Gulf to the Red Sea. Extending from the shore of the Persian Gulf westward for a distance of about 50 miles is the east-facing Oqair escarpment, exposing Neocene beds. One hundred miles farther west is the edge of the eastern margin of the Dahna sand ridges. Near this area most of the Eocene exposures are found. Another hundred miles westward are the Dahna sand dunes and the great west-facing escarpment of the Aruma (300

TxU

meters high and 600 kilometers long). Still another hundred miles to the west, the pre-Cambrian terrane occurs. (See figure 1.).

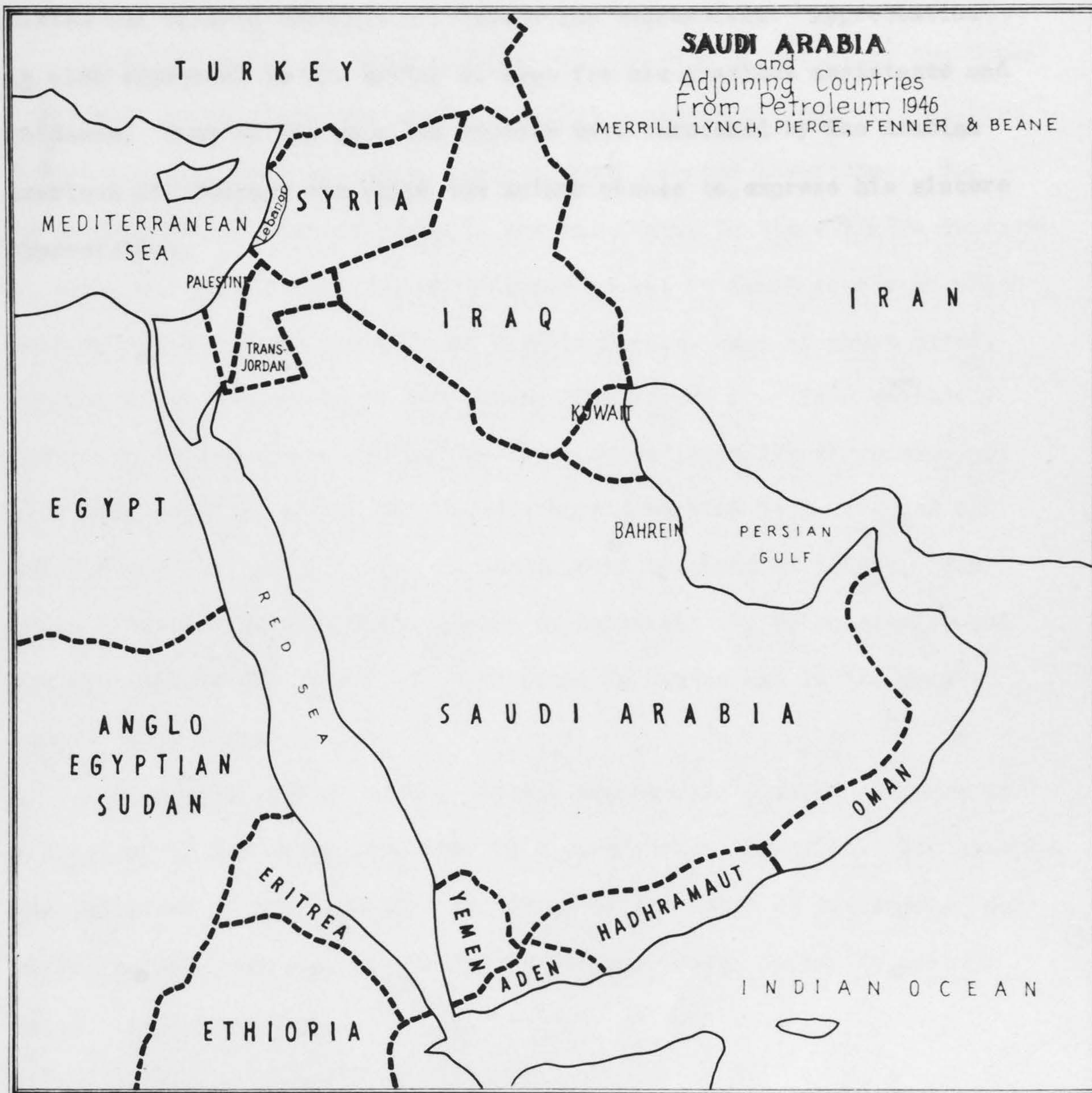

SAUDI ARABIA
and
Adjoining Countries
From Petroleum 1946
MERRILL LYNCH, PIERCE, FENNER & BEANE
TURKEY
SYRIA
Lebanon
MEDITERRANEAN SEA
PALESTINE
TRANS-JORDAN
IRAQ
IRAN
KUWAIT
BAHREIN
PERSIAN GULF
EGYPT
RED SEA
SAUDI ARABIA
ANGLO EGYPTIAN SUDAN
OMAN
HADHRAMAUT
ERITREA
YEMEN
ADEN
INDIAN OCEAN
ETHIOPIA
Plinio Alfonzo

Figure 1

ACKNOWLEDGEMENTS

The writer is deeply grateful to Dr. Hal P. Bybee, Dr. Don L. Frizzell, and Dr. H. H. Power who so kindly served as a thesis committee and offered valuable criticisms and suggestions. Appreciation is also expressed to Mr. Arthur H. Deen for his gracious assistance and guidance. Many of the maps and reports were furnished by the Arabian American Oil Company for which the author wishes to express his sincere appreciation.

566624

GENERAL DISCUSSION OF CRETACEOUS AND TERTIARY STRATIGRAPHY IN ARABIAN PENINSULA AND ADJOINING AREAS[1]

Upper Cretaceous

Aruma formation of Saudi Arabia: On the Arabian Peninsula the Upper Cretaceous Aruma formation consists almost entirely of well-bedded, grey to greyish-tan, fine to medium grained fossiliferous limestones. The formation extends east of Laila in central Arabia to the northern borders of Syria and Palestine. The northernmost point in Sauid Arabia at which this formation was measured is at Taisiya Plateau east of great Nufud. The thickness here is about 272 meters (See figure 2). In a southerly direction the thickness of the exposed section gradually decreases, and at a point east of Laila, just before this formation is overlapped by the Neocene Continental beds, it has thinned to about 22 meters. The Aruma formation is apparently absent in Hadhramaut in South Arabia, but the approximate equivalent of it is found in Dhufar and in the Oman range. (See figure 2).

A deep-well section of the coastal region also yielded evidence of a thinning of the Aruma formation in a north-south direction. For example, the thickness of the formation in Dammam on the coast of the Persian Gulf is 261 meters, whereas, at Abu Hadriya to the north, it is 569 meters thick. (See figure 7).

---

[1] The material presented in this part of the thesis was furnished by the Arabian American Oil Company. (General Discussion on Cretaceous and Tertiary Stratigraphy on the Arabian Peninsula and Adjoining Areas.)

Equivalent strata in adjacent areas: Lees and Richardson[2] reported that the Upper Cretaceous section in Western Iran consisted of about 5,000 feet of normal marine sediments and over 10,000 feet where the clastic facies is developed.

Lees also reported the presence of the Upper Cretaceous in Oman[3] and Dhufar[4] provinces in South Arabia. He did not give the exact thickness of the formation, but they are known to be less than those of Iran.

Cretaceous[5] sediments crop out intermittently along the east coast of Africa from the Gulf of Aden to as far south as Kenya. Upper Cretaceous limestones resting on ancient crystalline rocks are found on the island of Sokotra. Cretaceous beds also crop out in eastern British Somaliland; the thickness of those strata is approximately 1,450 feet.

In Palestine, Lower and Upper Cretaceous beds were found. The Lower Cretaceous, consisting of about 300 feet of mostly sandstone, overlie a poorly preserved Upper Jurassic section. The upper portion of the Cretaceous (Cenomanian and higher) has a thickness of about 800 meters, and it consists mainly of limestone.

In Lebanon, Upper and Lower Cretaceous strata have been identified. The Lower Cretaceous, (Neocomian-Aptian-Albian) has a thickness of about 600 meters. The Upper Cretaceous, including strata of Cenomanian and later age in the central Lebanon Mountains, consists of 4,000 feet or more of well-bedded limestone and chalk. These Cretaceous beds decrease

---

[2]Lees, G. M., and Richardson, F. D. S. Geol. Mag. No. 77 no. 7, p. 233.

[3]Lees, G. M. Geol. and Tectonic of Oman and of parts of Southeastern Arabia. Quaternary Genl. Soc. 1928, p. 607.

[4]Ibid, p. 605.

[5]Arabian American Oil Company report (general description of Cretaceous and Tertiary, p. 2).

in thickness toward the east, where they are less than 1,000 feet thick in the Ruba district west of Iraq. The thickness and character of the section in the Ruba district seems to be similar to the Upper Cretaceous section (Aruma formation) on the Taisiya Plateau, Saudi Arabia, where it measures 272 meters.

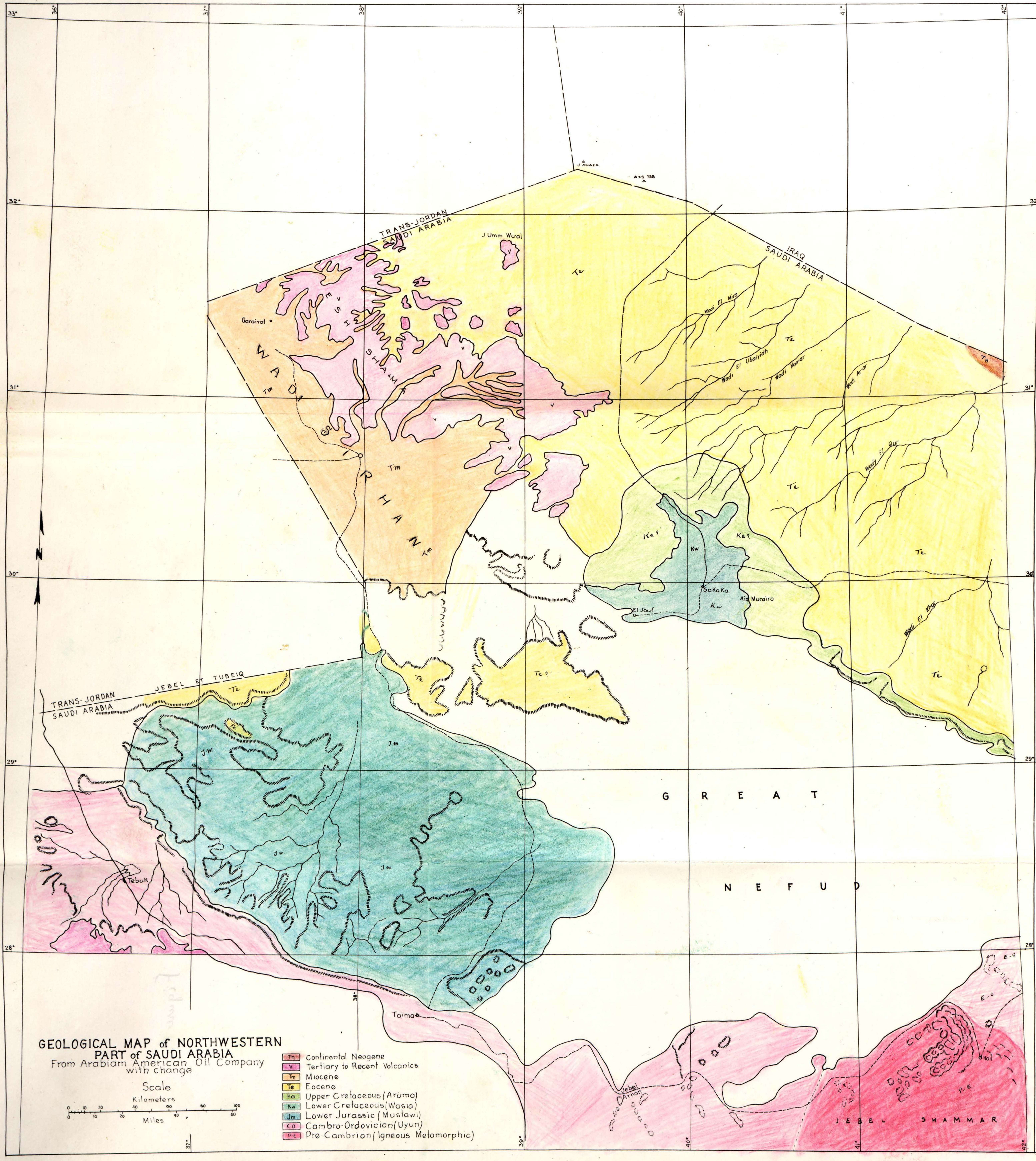
As previously mentioned, the Upper Cretaceous reaches its maximum thickness in central and western Iran where the section consists of about 5,000 feet of marine deposits and 10,000 feet of clastics. The Lower Cretaceous in central Iran has a thickness of about 3,000[6] feet.

Eocene

Eocene in Saudi Arabia: The Eocene beds of Saudi Arabia consist predominantly of limestone, although more than 300 feet of anhydrite is known on the Persian Gulf Coast between the Abqaiq dome and the Kuwait Neutral Zone. In the interior, the Eocene consists almost entirely of light grey to light greyish-tan, fine to medium grained limestone. In many places a large portion of this formation is crystalline limestone. The section is rather difficult to measure because of its massive character and very low dips. The total thickness of a section in the Ma'Aqala district is 715 meters. From Ma'Aqala southward the formation thins gradually. In Wadi Sahaba the thickness is 160 meters. South of Wadi Sahaba the Eocene strata are overlapped by the Neogene deposits. North of Ma'Aqala the thickness of the Eocene beds measured in Wadi El Batin is

---

6 The Arabian American Oil Company report (general discussion of Cretaceous and Tertiary in Saudi Arabia and adjoining areas, p. 4.).



GEOLOGICAL MAP of NORTHWESTERN PART of SAUDI ARABIA
From Arabiam American Oil Company with change
Scale
Kilometers
0 10 20 40 60 80 100
0 10 20 40 60
Miles
Tn Continental Neogene
V Tertiary to Recent Volcanics
Tm Miocene
Te Eocene
Ka Upper Cretaceous (Arumo)
Kw Lower Cretaceous (Wasia)
Jm Lower Jurassic (Mustawi)
C-O Cambro-Ordovician (Uyun)
P-C Pre Cambrian (Igneous Metamorphic)
TRANS-JORDAN
SAUDI ARABIA
IRAQ
SAUDI ARABIA
J. ANAZA
J. Umm Wu'al
Garaiyat
WADI SIRHAN
Wadi El Misra
Wadi El Ubaiyidh
Wadi Hamer
Wadi Ar-ar
Wadi El Qur
Wadi El Khor
SaKaKa
El Jouf
Ain Muraira
JEBEL ET TUBEIQ
TRANS-JORDAN
SAUDI ARABIA
Tebuk
Taima
Jebel Arnan
Hail
GREAT
NEFUD
JEBEL SHAMMAR

found to be 204 meters. Still farther north on the Saudi Arabia-Iraq borders the thickness seems to be in excess of 204 meters, although no exact measurement has been obtained. The Eocene beds of the interior of Saudi Arabia rest conformably on the Aruma formation (Upper Cretaceous) but they are unconformably overlain by the Neogene deposits of a continental origin.

In some coastal Persian Gulf areas the upper portion of Eocene outcrops; the known Eocene sections in several positions of this region are as follows:

Abqaiq	441 meters
Dammam Dome	382 meters
El Alat	637 meters
Abu Hadriya	833 meters

From these figures it will be noted that the Eocene increases in thickness toward the north; it is quite possible that the maximum depth of the Eocene basin of deposition was in the Persian Gulf region.

Eocene Outside Saudi Arabia: The Eocene beds are found to be widespread in regions adjacent to the Saudi Arabian Territory, as for example in Hadhramaut and Dhufar. The thickness of these beds in Hadhramaut is 600 feet.[7] In Dhufar the exact thickness is not known, but the beds of the Eocene series form the upper member of a limestone section which is approximately 16,000 feet thick. Rocks of this epoch outcrop in the British Somaliland; a thickness of 2,500 to 4,500 feet is known. These formations continue northward to crop out in Egypt. Farther northward they are also found in Palestine, the Lebanon Mountains and the Syrian Desert.

---

[7]The Arabian American Oil Company report (general discussion of Cretaceous and Tertiary in Saudi Arabia and adjoining areas, p. 4).

The Eocene beds in the foregoing regions and in north Arabia are widely distributed but have relatively small thicknesses. For example, in Palestine the Eocene strata have a thickness of about 950 feet, while in the Syrian Desert they measure about 1,000 feet. Farther east in Iraq and Iran, the thickness is considerably more and here attain a thickness of 5,000 to 10,000 feet[8] in Iran.

Oligocene

No Oligocene deposits have been found in Saudi Arabia, but they have been observed in Hadhramaut, Iran (Asmari limestone) and Iraq where the discovery of beds equivalent to the Asmari limestone were reported along the Euphrates River north of Hit and in the mountains in the vicinity of Palmyra.

Marine Neogene (Miocene and Pliocene)

The Neogene beds on the Arabian side of the Persian Gulf are very thin (60 - 300 meters) as compared with those of Iraq where the average thickness seems to be 5,000 - 6,000 meters. The average thickness of the deposits of this age on Saudi Arabian side of the Persian Gulf is about 1,000 feet. The Persian Gulf coastal region of Saudi Arabia persisted during the Neogene as a regional structural terrace on the Arabian foreland. Therefore, few sediments of this age accumulated on this structure. However, the Neogene sea seems to have transgressed this great terrace from time to time; the maximum extension of the sea westward in Arabia was about

[8] The Arabian American Oil Company report (general discussion of Cretaceous and Tertiary in Saudi Arabia and adjoining areas, p. 4).

100 kilometers from the present coast line. Farther west in Arabia the continental Neogene deposits are to be found.

Sections of the Neogene strata measured in a westerly direction show the following:

Hofuf Formation	25 - 110 meters
Dam Formation	40 - 70 meters
Hadrukh Formation	15 - 120 meters

The marine members in the Neogene section interdigitate with continental members; hence it is impossible to trace any one horizon for great distances.

Hadruck Formation: A section 20 meters in thickness measured on the coast between Jubail and Dammam consists mainly of marine limestone and shale with some sandstone. Farther west in the Qidan Abu Hadriya and Ain el Abd quadrangles the Hadruck formation is mostly unconsolidated, calcareous sandstone, greenish, gypsiferous clay, shales with occasional streaks of red clay, and fresh-water limestone grading into chert. The limestone generally contains shells of fresh-water Mollusca. Sandstone and chert intercalations are characteristic of the Hadruck formation.

Dam Formation (Miocene): The thickness (30 to 100 meters) and character of Dam formation varies considerably. However, certain characteristic marine beds have a remarkably widespread distribution along the coastal region. The best lithologic markers are the "Button Beds" and an associated Archaias bearing stratum which can be traced more or less continously from the south extension of Qatar Peninsula (24° 14' N, 51° 00' E) in a northwesterly direction to a point north of Er Rudaif (27° 28' N, 48° 30' E), a distance of about 450 kilometers. In a transverse direction and toward the interior the highly fossiliferous Dam series (50 to 70 Meters thick) sometime becomes entirely continental within a distance of 10 to 15 kilometers.

Hofuf Formation (Pliocene ?): This formation (thickness 30 to 100 meters) rests on the marine Dam formation near Hofuf, a town on the coastal east-facing escarpment. Here the formation has a thickness of 78 meters. The section consists entirely of continental deposits with a basal sandy conglomerate and an overlying series of conglomeratic sandstone, sandy limestone and shales. The reddish sands and sandy limestone which cap the Oqair and Dam escarpments have been assigned by some workers to the lower portion of the Hofuf series. The age of the Hofuf formation is not definitely known, but it may be Pliocene.

Continental Neogene

The Neogene continental beds can not be separated into different formations because of their homogeneous character. These deposits extend from the eastern edge of the Summan Plateau until they overlap the Eocene deposits along the Dahna Sand dunes. These usually consist of a series of lenticular reddish, reddish-brown to dirty grey, gritty clays, and clayey sand with beds of reddish-brown, grey, impure, sandy fresh-water limestone. These continental beds sometimes contain lenses of grey sandstone and pebbly beds. The fresh water limestone sometimes contains the shells of gastropods and Chara spore cases.

In the Red Sea area of Saudi Arabia, these continental beds are known to occur almost continuously along the shore of the Red Sea from Wajh in the north to Jazan in the south, but no definite data with reference to these exposures are available. On the Farasan Islands in the southeastern portion of the Red Sea a Miocene continental deposit containing much salt is known. Oil-seeps have been discovered in these deposits. A water well drilled at Jedda, Saudi Arabia, on the Red Sea coast, penetrated 200 feet of salt, possibly of Neogene age.

In Palestine and Syria the thickness of the Neogene marine deposits is very small when compared with that of the Persian Gulf region. The Neogene deposit may be thicker in the Dead Sea graben; no definite data are available. The Neogene sea seems to have connected with the Mediterranean Sea north of Iran and Syria where the marine deposits are found. The Arabian Shield stood high between the Dead Sea and the Persian Gulf and here no marine deposits accumulated. In the central and northern parts of Arabia the continental Neogene sediments accumulated.

Quaternary

On the coast of Persian Gulf raised beaches and flat-lying fossiliferous sandstones are common between Dharhran and Abu Hardriya. These beaches sometimes attain an elevation of 10 to 15 meters above sea level. They rest unconformably on Miocene deposits.

Cross-bedded soft sandstone forming hillocks is also common in the coastal region. These hillocks attain 30 meters elevation above sea level. The lower strata contain shell fragments, but usually the sandstones are unfossiliferous.

In the interior, extensive plains are covered by gravel which is believed to be derived from Neogene conglomeratic material. These residual gravels were left after the cementing material of the conglomerate had been disintegrated and removed by eolian action.

Caliche and detrital deposits, firmly cemented in place by calcium carbonate, are common in the interior (Summan).

The extensive gravel areas in Rub'Al Khali, such as the Hadibu and Abu Bahr plains, are probably the result of the erosion of the Neogene deposits. These gravels, consisting mostly of igneous, metamorphic, and hard sedimentary rocks were deposited during the Neogene after being derived from ancient rocks in the interior. These deposits have been considered to be either Upper Neogene, or Quaternary, according to the material upon which they are lying.

The Dibdiba gravels are found in Dibdiba plateau which lies between the neutral zone along the Saudi Arabian, Iraq, and Kuwait borders. This gravel extends westward as far as the Umm Er Radhuma well. The gravels ordinarily lie to the east of the Summan limestone areas, but often the two merge. These gravels are in part residual and partly outwash of flood-plain origin. The thickness varies; at Burq Esh Sherif in Wadi Al Batin it reaches a thickness of about 20 meters. The deposits consist of lenticular, crossbedded, coarse sandstone and gravels. The gravels are made up primarily of well-rounded pebbles of white quartz and black, igneous material.

The Summan limestone has a very wide distribution over eastern Saudi Arabia. It extends from north to south, east of and parallel to the Dahna sand dunes. It occupies an area of about 13,000 square kilometers. The limestone is a calcareous caliche, which has been derived from the underlying sediments. Although it overlies rocks of various age, it is primarily confined to the area underlain by post-Eocene sediments.

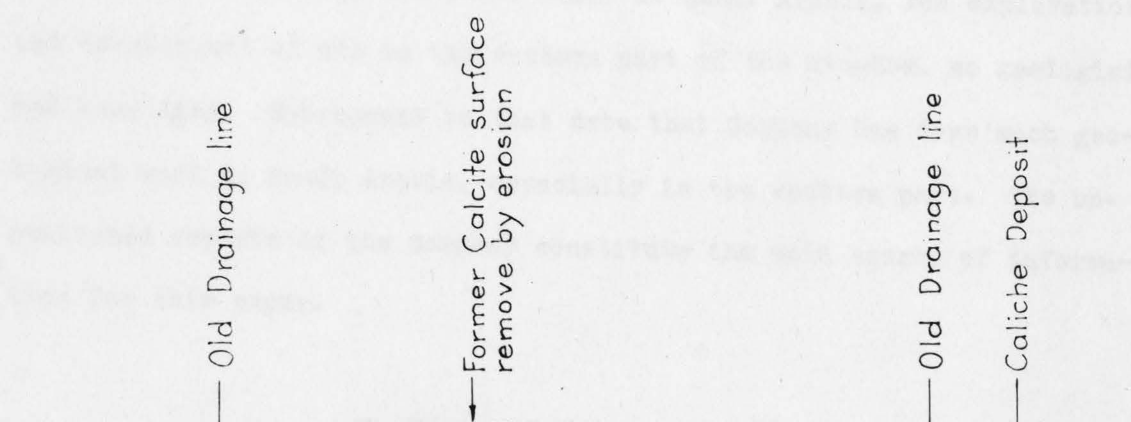
Miller, while on a reconnaissance survey of the Summan area with the Arabian American Oil Company, noticed a "fossil" type of old drainage line "Which so far as known to him has not been described as existing elsewhere".[9]

---

[9] Miller, Robert P. "Drainage Lines in Bas-relief", Journal of Geology, Volume 45, No. 4, p. 432-438.

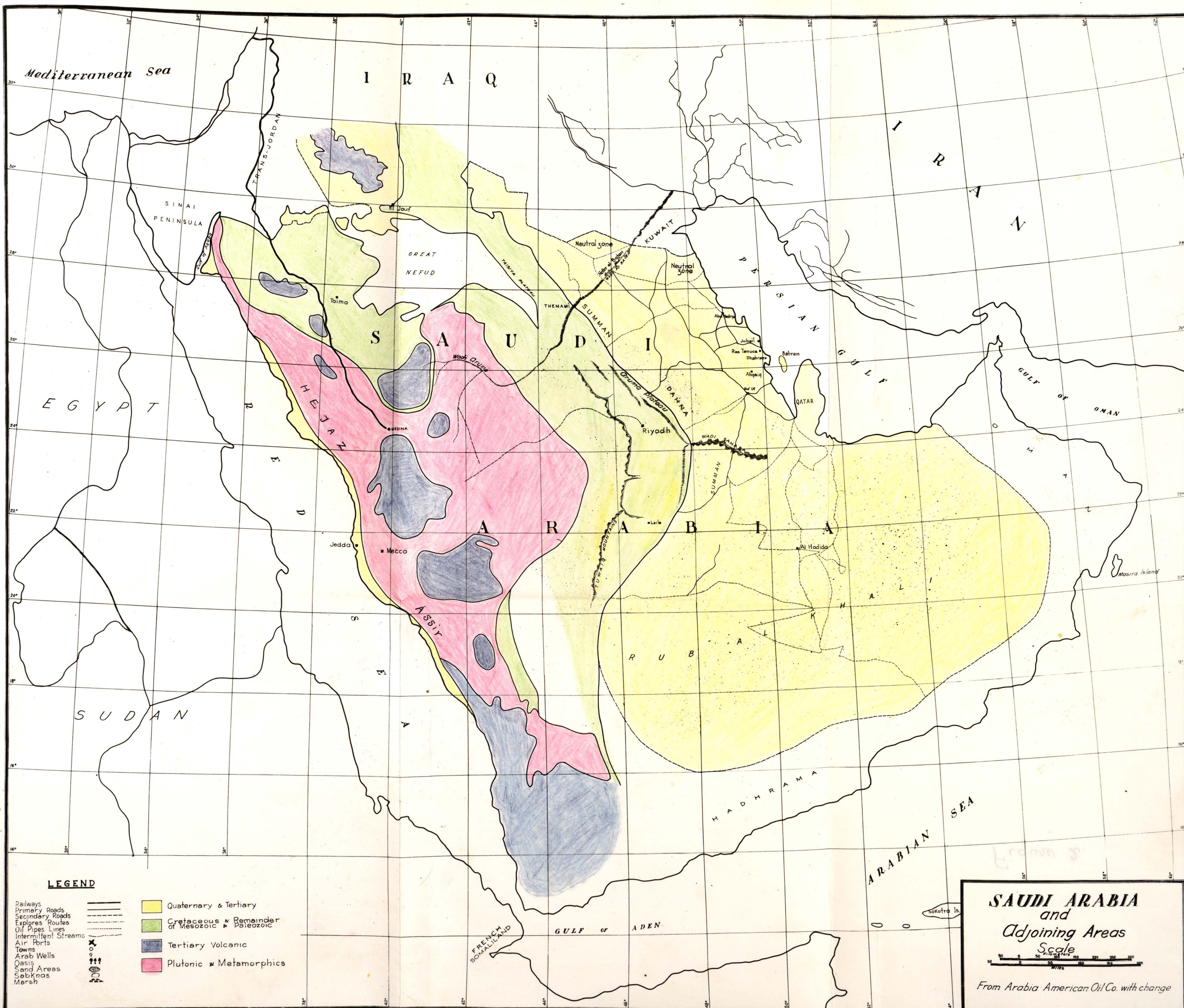
The streams stand higher than the area between them. These drainages form a bas-relief of dendritic pattern formed mostly of caliche materials. They are found in a slightly rectangular strip 350 to 400 kilometers west of the Persian Gulf, south of Darp Zubaida and east of the Dahna area. The drainage is mostly toward the east.

The origin of this high dendritic drainage may be explained as follows: the Summan region is a desert area of occasional rainfall. Some of the water running through the channels seeped downward. This water was returned to the surface by capillary action and evaporated, depositing caliche. The presence of this caliche in the drainage pattern resulted in differential erosion, and the areas between channels were eroded at a greater rate than in the channels. Therefore, caliche-hardened rocks of the drainage pattern are elevated above the adjacent topography, constituting the distinctive topographic form which Miller termed "suspendritic drainage" (See figure 4).



Ideal section. Profile across two drainage lines before being removed by erosion. The present surface is shown in full line (From Journal of Geol. May-June 1937 P. 433)

Figure 4



Mediterranean Sea
IRAQ
IRAN
TRANS-JORDAN
SINAI PENINSULA
Gulf of Aqaba
El Jauf
GREAT NEFUD
Taima
TAISIYA PLATEAU
Neutral zone
KUWAIT
Neutral zone
THEMAMI
SUMMAN
PERSIAN GULF
SAUDI ARABIA
Wadi Aruma
Aruma Plateau
DAHNA
Jubail
Ras Tanura
Dhahran
Abqaiq
Bahrein
Hofuf
QATAR
GULF OF OMAN
OMAN
EGYPT
HEJAZ
MEDINA
Riyadh
WADI SAHBA
SUMMAN
RED SEA
TUWAIQ MOUNTAINS
Laila
Jedda
Mecca
Al Hadida
Masira Island
ASSIR
RUB AL KHALI
SUDAN
HADHRAMA
ARABIAN SEA
FRENCH SOMALILAND
GULF OF ADEN
Sokotra Is.
LEGEND
Railways
Primary Roads
Secondary Roads
Explores Routes
Oil Pipes Lines
Intermittent Streams
Air Ports
Towns
Arab Wells
Oasis
Sand Areas
Sabknas
Marsh
Quaternary & Tertiary
Cretaceous & Remainder of Mesozoic & Paleozoic
Tertiary Volcanic
Plutonic & Metamorphics
SAUDI ARABIA and Adjoining Areas
Scale
Kilometers
Miles
From Arabia American Oil Co. with change

Northeast region: The drainage which extends from Anaza southward divides this area into eastern and western regions. The eastern area is characterized by the presence of numerous, intersecting wadis forming a dendritic pattern; the drainage is northeastward to the Tigris-Euphrates Valley. In the western region, the wadis are shorter and deeper, but out dendritic pattern; these drain southwestward to Wadi Sirhan. The underlying strata of the northeastern territory consisting of limestones, sandstones and shales are of Eocene age; the dip is northeastward. Near Wadi Sirhan the sediments are covered with basaltic lava of probable Quaternary age.

Southwest region: The main topographic features of this region are due in large part to the erosion of low-dipping sediments ranging from Cambrian to Miocene in age. Three prominent, southwest-facing erosional escarpments have been developed, namely, the Sirhan, the Tubeiq, and the Taima.

The Sirhan escarpment extends from near Qasr Asaraq in Trans-Jordan to the vicinity of Jau Muraira in Saudi Arabia, a total distance of over 400 kilometers. The strike from the northernmost point, near latitude 300 degrees north, is approximately 40 degrees west of north. South of this point, however, the strike changes abruptly to one almost due east. East of Jau Muraira, a lower escarpment continues in a northwestern to southwestern direction, thereby forming the southwest facing cliffs which vary in height from 200 to 250 meters.

Tubeiq Escarpment: It extends from the southern border of Trans-Jordan to the western margin of the Great Nefud, forming a conspicuous south-facing escarpment for a distance of almost 300 kilometers. There is reason to believe that this escarpment continues under the Great Nefud Dunes, and is continuous with one of the escarpments west of Dahna. The average height of the Tubeiq escarpment is about 200 meters.

The third escarpment is known as the Taima; it extends from the northern side of the town of Taima northwestward for a distance of about 250 kilometers. Like the Sirhan escarpment, it trends approximately 40 degrees west of north from Taima, but near Taima the direction changes to an easterly one; the height is about 225 meters. With the exception of the presence of several wadis which trend northeastward, the area between the Sirhan and the Tubeiq escarpments is a uniform, flat plain rising gradually to form with the Sirhan escarpment the Wadi Sirhan. Therefore, Wadi Sirhan is partly structural and partly erosional in origin.

The surface between the Tubeiq and Taima escarpments is quite different from that previously described. It is dotted with rounded hills and hillocks forming a conspicuous feature of this area. Some of these hills are brightly colored in shades of purple and red.

South of the Taima escarpment, and extending eastward to Hail, the region is characterized by its high, flat-topped hills, such as Jebel Arnan, and tortuous deep valleys. This area is also distinguished by the presence of numerous rock pinnacles and spires, ranging from a few inches to 20 meters in height; these erosional remnants consist of hard, cross-bedded sandstones.

The moving dunes known as the Great Nufud, which occupy an area of about 50,000 square kilometers, are notable because of their huge, conical shape. The dunes on the west and southern margins of this terrane range in color from light yellow to brown near the town of El Jauf, but south of the Tubeiq escarpments, the color becomes bright red, and east of Taima, the color again becomes light yellow to brown.

Origin of Wadi Sirhan and Great Nufud: The orientation and form of the sand dunes of the Great Nufud indicate that the direction of the prevailing wind is from the west. The light yellow to brown colors of these dunes, near El Jauf, and Sakaka, and their bright red color south of the Taima escarpment give reason to believe that the wind carries these sand grains from the weathering sediments of the Wadi Sirhan escarpment and from the Mustawi formation. Therefore, one can safely say that the Great Nufud and Wadi Sirhan which receive many streams but which have no outlet to the sea (See map), are due to the disintegration and erosion of the strata in Sirhan region and the concentration of the derived material in the great Nufud area.

Cambro-Ordovician (?) (Uyum Formation): A striking change in lithology appears near the lower margin of Taima escarpment. The rocks in question consist of white and red cross-bedded sandstones intercalated with green and red, sandy clays. These beds are characterized by the presence of joints filled with iron oxide. In places at the surface, large irregularly-shaped boulders of almost pure hematite can be found. No fossils have been obtained from the Uyum formation. The thickness of this sequence south of Taima is unknown, but the presence of similar lithologic materials in excess of 300 meters in the nearby mountains is reason for assuming a thickness of at least this figure.

Lower Jurassic (Mustawi Formation): A thick sequence of Lower Jurassic sediments (Mustawi Formation) was found in the lower margin of Jebel Tubeiq. The sediments consist of dark red to purple, cross-bedded sandstones and shale. The contact with the overlying Eocene marls and limestones is unconformable. The Eocene beds dip only slightly to the northeast, while these beds show a more pronounced dip in the same direction. Similar beds are found all the way from the Tubeiq Escarpment to the Taima Escarpment, a distance of from 50 to 200 kilometers.

These beds are unfossiliferous, but their similarity in lithology to the strata of the Mustawi formation is cause for their being assigned to the Lower Jurassic.

Jurassic-Cretaceous (Riyadh (?) Formation): Strata which might be referred to the Jurassic-Cretaceous may be found at the base of the cliff upon which stands the Fort of Jauf. They consist of several meters of hard, white, siliceous limestone and gray shales. These beds are unfossiliferous. Since they underlie the Wasia strata and are lithologically different, they might be considered to be the equivalent of the Riyadh formation.

Lower Cretaceous-(Wasia Formation): Between the towns of Jauf and Sakaka, a thickness of approximately 200 meters of white to red, coarse, cross-bedded sandstones and shales are known. With the exception of numerous fragments of silicified wood, these beds appear to be entirely unfossiliferous. They are probably of continental origin. Small, spherical, iron oxide nodules occur abundantly in some parts of the formation.

The reference of these beds to the Lower Cretaceous is based entirely on lithologic similarity to beds of known stratigraphic position in other areas.

Upper Cretaceous: Near the northern rim of the Wadi Sirhan, north of the town of Sakaka, a considerable thickness of rather massive cliff-forming limestone is found. These beds are unfossiliferous, except for a few unidentified marine fossils. The fossils furnish no definite evidence as to the age, but from lithologic evidence this formation might be classified as Upper Cretaceous (Aruma formation). The Aruma formation of the Wadi Hauran in quite similar structurally and lithologically to these strata.

Eocene of Northwestern Saudi Arabia: The northwestern part of Mejd province, which is considered geologically as a part of the Syrian Desert, is mostly underlain by limestone, of probable Eocene age. The exact thickness of these marine sediments is not known, but it is somewhat less than that of the Eocene known in the Persian Gulf province.

In Wadi Mejinah (fossil locality S-750)(See map) some poorly preserved specimens of *Operculina* cf. *complanata* Defrance and *Amphistegina* (?) sp. were found. At Jebel Tubeiq, a thickness of approximately 100 meters of predominantly marl and silicified limestones was measured. A small species of Nummulites was collected from the upper portion of the silicified limestone; *Venericardia* was found in the lower marly part of this sequence. These give little evidence regarding the exact age of the strata, but are strongly indicative of the Eocene.

Continental Neogene: At Jebel Debusa, near the boundary with Iraq, a considerable thickness of continental deposits rest upon marine limestone. Its age has been determined from fossil leaf impressions. On the basis of the probable occurrence of *Schizaster parkinsoni* in the Sirhan formation, the nearest equivalent in the Persian Gulf region would be the Dam formation.

Miocene (Sirhan Formation): In the northern part of Wadi Sirhan, near Garaiyat, is a section of sedimentary rocks which gently dip toward the east. The formation, in its lower part, consists of sandstone overlain by basalt. The basalt is overlain by thin-bedded sandstone. On the eastern rim of Wadi Sirhan the upper members are covered by the Harra Lavas. The average thickness of this section is about 150 meters. The entire sequence is called the Sirhan formation. It has been divided into (a) lower marl member, (b) the Garaiyat lava, and (c) the sandstone member.

Lower marl member: At the type locality, the base of this member is not exposed. Here the strata consist of from 10 to 30 meters of folded white, sandy marl. A short distance to the east, the upper sandstone member rests unconformably upon this member. Similar beds can be traced south and west of the type locality.

The fossils found in this member consist mostly of echinoids. The following species have been identified: Scutella sp., Schizaster, probably parkinsoni Defrance, Agassizia near scrobiculata Valen., and Brissoides (?) sp. near B. meliteses Creq.

Garaiyat lavas: The middle member of the Sirhan formation has been studied on the small hill near the northern exposure of the Garaiyat outcrop. At this locality a section of 35 meters in thickness highly weathered, olivine-bearing basalt, rests upon the lower marl member. Near the middle of the sequence, these lavas are traversed by thin aplite dikes, and in some place an amygdaloidal phase can be found. The presence of basalt boulders in the conglomerate at the base of the upper sandstone member may indicate a considerable erosional interval before the deposition of the upper sandstone section.

The Garaiyat basalt can be easily distinguished from the Harra basalt, since the later is very resistant, while the Garaiyat is relatively soft.

A few kilometers west of the type locality the Garaiyat the lavas are reduced to a meter in thickness and ultimately disappear. The north-south extent of these Miocene lavas is not known.

Upper sandstone member: The upper member of the Sirhan formation consists of fine, light brown to white, calcareous sandstone, with a few meters of secondary gypsum near the top of the section. The thickness of this member is about 65 meters. Northwest of Garaiyat, brown argillaceous sandstone appears in the section. This member can be easily traced north and south of the Wadi Sirhan rim. The cap rocks of the higher margins of the western rim of Wadi Sirhan may be equivalent to this member.

Quaternary (?) Harra lavas: Along the northeastern rim of Wadi Sirhan an extensive series of olivine-bearing basalts occurs. At Jebel Umm Wu'AL to the northwest, the lava cover has been removed and sediments of probable Eocene age are exposed. The thickness of the lava is about 100 meters; the flows are transversed by numerous, thin aplite dikes. Northeast of Garaiyat near the border of Trans-Jordan in the Jebel Misma region, the lava forms conspicuous peaks such as Jebel Abu Rasain.

STRATIGRAPHIC SECTIONS OF UPPER CRETACEOUS, EOCENE, NEOGENE, AND QUATERNARY STRATA ALONG WADI AL BATIN AND WADI ARUMA IN SAUDI ARABIA[11]

Upper Cretaceous Section

The information available is shown in graphic form in figure 3.

This section is 290 meters thick, divided into four different zones. The three lower zones are of limestone. The fourth and the upper one consists of shale.

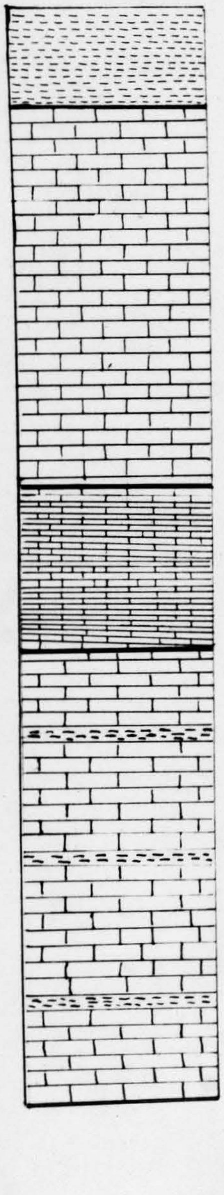
Eocene Section

The Eocene section was measured along Wadi Al Batin between Themani and Hafer Al Batin. The lower zone consists of 172 meters of hard crystalline limestone and grey to white, hard, silicified limestone with interbedded chert. In general, this zone contains more fossils than either of the other two. In its upper part, Amphisorus remains were found. In the middle and the lowest portions Alveolina-bearing beds are known.

The following is a detailed description of this section made by the Arabian American Oil Company. The middle zone of this section is about 80 meters thick. It is similar in lithology to the upper zone; more abundant but poorly preserved fossils such as various gastropods and cerithiids, with calcite replacements occur. In the upper portion of

[11]These sections were measured by the Arabian American Oil Company (measured stratigraphic sections at Upper Cretaceous, Eocene, and Quaternary along Wadi Aruma and Wadi Al Batin, Report).

Meters



Yellow to yellowish brown silts and clays with compressed gastropods, corals and rudistids. 25

Grey to Buff limestone with rough weathered surface; foraminiferal at the top, much of this zone is covered by Dahna sands. 100

Thin Bedded limestone with interbedded fossiliferous yellow marls and clays well preserved; diagnostic Upper Cretaceous fossils are abundant 45 Two separate horizons are present both carrying rudistids Cyclolites and other forms.

Composed chiefly of gray to white impure fossiliferous limestone. The basal section carries 120 Ammonites and Echinoids. Locally developed marly zones bear Cyclolites and rudistids

Total 290 meters

COMPOSITE COLUMNAR SECTION of UPPER CRETACIOUS along WADI AL BATIN and WADI ARUMA

From surface data supplied by Arabian American Oil Co.
Scale 1 inch = 25 meters

Figure 3

this zone the blue grey limestone commonly contains Mollusca. Most of the limestone contains calcite crystals.

The uppermost zone of about 52 meters consists of alternating strata of hard, soft, grey to white limestones and soft to hard chalky limestone. The uppermost part of this zone is largely unfossiliferous, although a few gastropods have been noted. Near the middle there are some traces of small fossils; in the lower portion these are fairly abundant but poorly preserved.

A detailed stratigraphic section of Eocene strata along Wadi Al Batin, between Themami and Hafer Al Batin follows. The thicknesses are in terms of meters.

4.0	Hard, brown or yellow limestone.
7.0	Blue-grey to grey, rubbly limestone or dolomite.
2.0	Partly covered, white, chalky, hard limestone.
2.1	Fine to medium-grained limestone.
3.5	Mostly white to grey, hard limestone with gastropods.
3.0	White, chalky limestone.
1.8	Blocky weathering white to grey limestone.
5.0	Limestone topped by blocky weathering limestone.
0.4	Hard, white, chalky limestone; finely porous, with traces of small fossils.
0.3	White, chalky limestone; soft, thin-bedded.
1.0	White, hard, chalky limestone ledge.
1.0	Mostly covered.
1.2	Hard, white, chalky limestone in massive ledges.
0.5	White, chalky limestone.
1.0	Massive ledge of white, chalky limestone.

7.0	Alternating hard and soft, chalky limestone; well bedded, with fairly abundant, poorly preserved fossils.
1.2	Hard, white, chalky limestone. Elevation 422 m.
4.0	Alternating hard and soft, chalky limestone.
5.0	White, hard limestone, somewhat stained with manganese.
0.4	Hard limestone, locally recrystallized.
1.6	Partly covered, somewhat mottled limestones.
0.6	White, hard limestone with calcite replacement of fossils.
0.6	Somewhat soft, whitish-grey limestone.
0.4	Top of ledge of blocky, hard, white to grey limestone with yellow stains; calcite lumps on surface.
0.4	Shale and chalky limestone.
1.2	Chalky limestone with yellow streaks; mollusks rather common.
1.0	Quite porous limestone with yellow streaks.
0.8	Ledge of chalky limestone.
0.8	Chalky limestone with small cerithiid.
0.6	Same as overlying.
1.6	Rubbly weathering, chalky limestone with some soft members; gastropods present.
2.2	Covered.
2.5	Blue-grey limestone with some yellow streaks, rubbly weathering with calcite crystals; forms a ledge; mollusks present.
3.3	Covered. Base of zone of slumping.
3.0	Very fine grained, somewhat porous limestone.
9.0	Essentially slumped.
2.8	Alternating hard and soft chalky limestone; upper part contains gastropods.

0.5	White, hard, chalky limestone with small poorly preserved, turreted gastropods.
0.7	Covered.
0.5	White, chalky limestone with minute pink traces; slightly porous.
0.3	Covered.
1.0	Massive ledge of white, chalky limestone; geodal calcite present.
1.6	White, chalky limestone, nearly massive; forms a prominent ledge.
1.4	White, chalky limestone, some traces of yellow stain; upper 0.4 m. contains fossils.
0.1	Softer material.
0.3	White, chalky limestone with fossils.
1.2	Hard ledge of chalky limestone.
1.0	Hard ledge of white limestone with some calcite lumps.
2.0	Hard, white limestone in beds roughly 0.33 m. thick.
2.5	Partly covered. Somewhat porous limestone with calcite replacement of fossils.
1.4	Hard ledge of white limestone, with indeterminate fossils.
1.6	Hard limestone, in part porous, forming a ledge; with small and turreted gastropods.
1.5	Covered.
1.8	Somewhat porous hard limestone.
2.0	Hard, white bed of chalky limestone with foraminifera.
2.2	Massive, chalky limestone.
0.8	Hard ledge of chalky limestone.
2.0	Limestone, somewhat porous, rubbly, capped by 0.1 m. of hard, yellow, massive limestone; top of definitely hard layers, softer and more easily eroded material above this interval; with marble size concretions near top.

1.7	Mostly covered, but probably blue to white marly limestone.
5.2	Limestone grey to white, rubbly weathering, somewhat slumped; slightly silicilied on some surfaces; contains foraminifera.
1.5	Hard, white, crystalline limestone, with foraminifera on weathered surface.
3.5	Grey, crystalline limestone, rubbly weathering; coiled foraminifera in lower part of bed.
1.0	Covered.
4.0	Massive, chalky limestone; top forms a bench.
3.0	Poorly exposed cream-colored limestone.
0.4	Hard, cream-colored, crystalline limestone, locally replaced by large, ellipsoidal chert bodies.
2.0	Hard, white limestone, somewhat chalky; hill badly slumped.
5.0	Alternating hard and soft, chalky limestone.
3.0	Soft, rubbly, white limestone, capped by a chert body.
5.0	Hard, rubbly limestone, grey-colored; locally altered to chert.
1.7	Porous, light grey limestone with traces of small fossils.
3.2	Grey, medium crystalline, hard limestone; upper portion laminated with traces of chert.
1.5	Grey, crystalline limestone with calcite lumps; local chert patches occur in beds 0.2 m. thick, mostly confined to lower portion; Amphisorus present.
0.2	Grey crystalline dolomite.
2.3	Covered.
12.5	Grey limestone, somewhat recrystallized, rubbly weathering, with some chert in place; Alveolina beds 1 to 2 m. below top; uppermost bed partly replaced by brown chert.

2.0	Cream-grey limestone, somewhat porous, with calcite lumps; numerous poorly preserved foraminifera present.
2.0	Partly covered grey to yellow, porous, rubbly limestone.
5.0	Grey, massive, rubbly limestone, with poorly preserved fossils.
1.2	Fine-grained, cream-colored limestone, in part replaced by chert; in part foraminifera coquina; forming ledges.
1.6	Rubbly, mottled limestone, with rare Alveolina.
1.2	Recrystallized grey limestone.
2.0	Limestone; mostly covered with chert, pebbles, and regolith at top.
2.0	Grey to brown, massive limestone, with some calcite stringers; poorly preserved fossils present; ledge forming.
2.1	Same as below; with poorly preserved foraminifera.
2.9	Fine-grained, white limestone with foraminifera, forming a hard ledge; poorly preserved fossils include Alveolina.
3.6	Fine-grained, white limestone, with numerous calcite crystals.
0.1	White, crystalline limestone.
1.5	Ledge of grey, crystalline dolomite.
1.4	Dolomite as above.
2.3	Covered.
0.4	Fine-grained, dark grey, recrystallized dolomite; grey fine-grained limestone.
3.3	In part rubbly and in part blocky weathering; upper 0.5 m. a hard ledge of white, fine-grained limestone with manganese stains.
Total 204 meters	

STRUCTURE OF THE ARABIAN PENINSULA[12]

The "Arabian Shield", consisting of old rocks, is a most significant factor in the genesis of the Arabian Peninsula. This, together with the Pre-Cambrian series of Egyptian Sudan, which joined Arabia to the west, forms a more or less uniform Arabian-Nubian massif. This massif represents an uplift, sloping on the one hand to the west toward Nubia and on the other hand towards Arabia in the east. Before the raising of this Arabian-Nubian mass it was probably covered in early Paleozoic times by the lower part of the terrestrial Nubian sandstone. After the upheaval the central part, which forms the highest point in this mass, was slowly eroded and Paleozoic-Mesozoic marine sediments were deposited on this shield. They can be recognized definitely on the northern borders of the shield in Egypt, Sinai, Trans-Jordan, and Great Nufud of northern Saudi Arabia. These sediments, little disturbed, are resting upon the Arabian shield. (See figure 6. Zone "2").

This region is surrounded by a zone of folded rocks (figure 5, Zone "3"), which extends from the northern part of Egypt through Sinai, Syria, and the Iraq Depression (syncline). It then passes through the Persian Gulf to Arabia where it forms the Rub Al Khali depression (Zone "3a"). This zone of folding disappears at the foot of Sabea Plateau in the eastern part of Yemen territory.

Picard[13] believes that these folded strata form another synclinal

---

12The material preserved in this part of the thesis is a summary from L. Picard "on the Structure of the Arabian Peninsula," The Geological Department, Hebrew University, Jerusalem Series 1, Bulletin 3, 1937.

13Picard, L. The Geological Department, Hebrew University, Jerusalem Series 1, Bulletin 3, page 2.

trough around the south Mediterranean region (North Sinai and Palestine Coastal Zone) analogous to the Iraqian Depression which is largely obscured by the Quaternary faulting and Recent deposition of sediments.

The next zone is one of severe folding. Zone "4" passes through the western part of Iran, Northern Iraq, and Syria, and extends westward to Cypress Island in the Mediterranean. This zone crosses the Persian Gulf to form the Oman range of mountains on the Arabian Peninsula. These mountains, characterized by intense folding, obviously constitute a continuation of the Zindon Range of Iran.

The ancient crystalline rocks of the southern part of the Peninsula, the similar rocks on the Island of Sokotra, and those of Somaliland in east Africa combine to form what Picard[14] called the Arabo-Somali mass.

This Arabo-Somali mass constitutes Zone "2a", which can be compared with Zone "2" of the Arabian-Nubian mass as regards their stratigraphic and structural relationships. The Arabian American Oil Company Report[15] supports this assumption.

The "Sabea Block" (or "Block of Yemen-Abyssinia") includes the elevated major part of Yemen Province, Southwestern Area, where there is considerable evidence of volcanic activity. It extends across the Red Sea and has its greatest extent in Abyssinia. This block is believed to have formed a continuous plateau that separated the Arabian-Nubian and Arabo-Somali masses, and which must be considered as a separate structural element. The uplift of the Sabea block took place between the Eocene and Neogene times. It is now crossed by three grabens, namely, the Rift Basin

[14]Picard, L. The Geological Department, Hebrew University, Jerusalem Series 1, Bulletin 3, page 2.

[15]Arabian American Report on general discussion of Cretaceous, Tertiary and Quaternary of Saudi Arabia and adjoining lands, page 5.

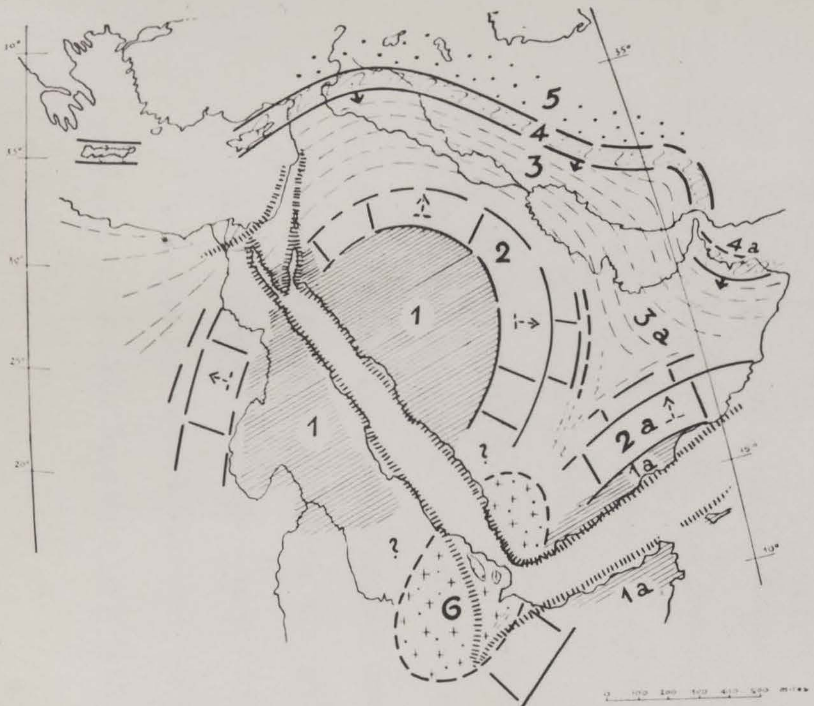


Fig. 1

Structural Sketch Map of the Arabian Peninsula and Surrounding Countries.

(For the purpose of clarity the younger volcanic areas have been omitted from the map.)

1. massifs: 1 arabo-nubian; 1a arabo-somali
2 Zone "tabulaire": 2 arabo-nubian; 2a arabo-somali
3. Zone of simpler folding (autochthonous); 3a Rhub al Khali
4 Zone of complex folding (nappes); 4a arc of Oman
5 Median Mass ("Zwischengebirge")
6. Block of Yemen—Abessinia ("Sabea")

Rift-faultings

direction of folding-movements

dip of zone tabulaire

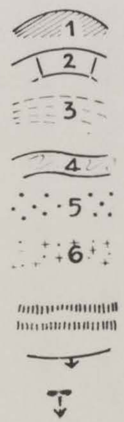


Fig. VI

Fig. 2

Cross Section from Nilus (SW) to the Persian Gulf. (NE).

Length : 1 : 10 millions; (10 mm—100 km)

Height 50 times length. (10 mm—2 km)

planed on data on de Böckh, Lees & Richardson, Cheesman, Cox, Hume, R. Newton, Philby, Campbell-Smith, v. Wissmann.

Fig. 3

Diagrammatic section from the Sudan (SW) to Persia (NE) crossing the Arabo-Nubian socle, the Red Sea Graben and the Mesopotamian geosyncline.

Fig. 4

Diagrammatic section from the Mediterranean (NW) to Hadramaut (SE) crossing the Rift valleys of the Dead Sea and of the Wadi Sirhan, the Arabo-Nubian massif of old rocks with its table lands, the Rhub al-Khali syncline, and the Arabo-Somali massiv (South Arabian marginal swell).

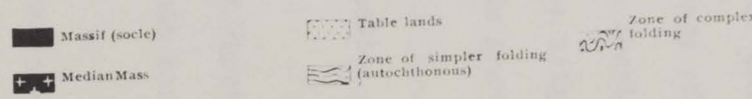


Figure 6

From "on the Structure of the Arabian Peninsula", Geol. Dept., Hebrew Univ., Jerusalem, Series 1, Bull. 3, pp. 10 & 11.

of East Africa, the Gulf of Aden, and the Red Sea.

Assir province, which is located in the southwestern part of Saudi Arabia, is a higher block than the Sabea block, but the inadequacy of information with reference to the extension of the Arabian-Nubian massif, to the south, prevents the postulation of hypotheses concerning its origin.

The tectonic movements responsible for the structure of the Arabian Peninsula are believed to be as follows:

(a) Movements in Paleozoic-Mesozoic mainly of epeirogenetic character (and still noticeable in the Cenozoic).

(b) Folding of Zone "3" (See figure 6) evidenced in the Upper Cretaceous of Oman, but, in the rest of the Peninsula strata from the Middle of Tertiary into the Quaternary.

(c) The most pronounced phases of faulting (Zone "4") are observed in the Tertiary to Quaternary rocks, and at this time the most extensive vulcanism took place.

GEOLOGICAL HISTORY

During the Paleozoic era the Arabian Peninsula was connected with Africa by the Arabo-Nubian and the Arabo-Somali massifs (See figure 6). The Mesozoic seas also connected the Arabian lands with Africa. Arabia was connected with Asia during the Mesozoic. The Persian Gulf Seas extended to cover the eastern and northern parts of Arabia. These seas advanced intermittently to meet the Mesozoic seas of the Mediterranean area. The Persian Gulf seas and the Mediterranean seas in their advance and retreat over the Arabic shield deposited strata of their respective ages, but the thickness of these strata show that the Arabic shield either stood most of time as an island or as a basin of a shallow sea.

During Tertiary, especially, Eocene, the same conditions existed. The thickness (10,000 feet) of the Mesozoic and Tertiary strata in the Persian Gulf region indicate that this area was a site of much subsidence during the Mesozoic and the Tertiary. The thickness of these strata outside the Persian Gulf during those ages were of less depth.

During the Neogene, the Arabian Peninsula was high above the sea level and no marine sediments were found except in narrow strips on the Persian Gulf coast and the Red Sea. The marine Neogene sediments formed in the Persian Gulf Coast show that this part of Arabia was a huge terrace where the Neogene seas extended and retreated intermittently. The connection between the Mediterranean and the Persian Gulf Sea during this time was north of the Arabian shield. All the known Neogene sediments of central and north Arabia have been identified as of continental origin.

Sometime between Eocene and Quaternary, the southern and western portions of Arabia became completely separated from Africa, due to the development of the Gulf of Aden and the Red Sea. Since then, all the sediments formed on the Arabian Peninsula seemed to be of continental origin.

OIL DEVELOPMENT

STRUCTURAL FEATURES OF THE SAUDI ARABIAN SIDE OF THE PERSIAN GULF[16]

The oil fields in Arabia, as well as those of Iran and Iraq, lie on the flanks of a deep, structural trough formed by the southwestern thrust of the forces which formed the Alps-Himalaya System, culminating in the Pliocene epoch, against the thick series of sediments dipping gently away from the Arabian shield. This trough extends from a point on the Turkish-Iraq borders to the boundaries of southern Arabia. It has an area approximately as great as that of the great plains in North America. The width of this trough is about 500 miles.

The axis of this trough lies in the Persian Gulf parallel to and near its eastern shore, and it apparently strikes northwest across Iraq to a point approximately midway between Mosul and Bagdad.

The oil fields of Iran and Iraq occur on the northeastern, steeply-folded flank of the trough; those of Arabia (Kuwait, Saudi Arabia, Bahrein, and Qatar) on the southwestern and gently-dipping flank of the Persian Gulf trough. The reservoir rocks of the fields of Iraq and Iran are limestones of Eocene to Miocene ages. Those of the fields on the Arabian flank are likewise of limestone, except for the immense Burgan field of Kuwait which is sandstone, and these are of Jurassic and Cretaceous ages. Reservoir conditions on the Arabian side are due to the porosity of the limestone.

---

16 The material presented in this part of the thesis was furnished by the Arabian American Oil Company (Structure in Saudi Arabia).

Dammam Dome

The location of the Dammam Dome is latitude 26° 14' north and longitude 50° 08' east. (See figure 7).

This conspicuous topographic feature has a maximum elevation of about 167 meters above sea level. The dome is oval-shaped; strata of middle Eocene age are exposed near the center of the structure, whereas on its periphery rocks of Miocene age are found. The intermediate slopes are clearly visible; they consist of gently dipping Eocene rocks. Four kilometers westward from the apex there crops out a west-facing rim-rock of nummulitic limestone which rests on shaly marls known as the Shark Tooth Shale. The dip slope on the outer periphery of the structure is about 1/5 degree. The rim-rock and the outward dipping limestone beds clearly show the outline of this structure. The distance from the rim-rock in the north to the edge of the rim-rock in the south is about 14 kilometers, whereas the east-west or short axis width is about 10 kilometers.

The numerous slump features due to solution of the Eocene and Upper Cretaceous rocks make it difficult to define the exact configuration of the apical area of this structure. Some of these solution features have a relief of 100 meters or more. Evidence from well records shows that numerous faults are present, but their relationship to each other and to the dome are not as yet clearly understood.

Abqaiq Dome

The location of the Abqaiq Dome is latitude 25° 65' north and longitude 49° 41' east.

The Abqaiq Dome is located in the midst of large sand dunes, a northward extension of the Jufura Nufud.

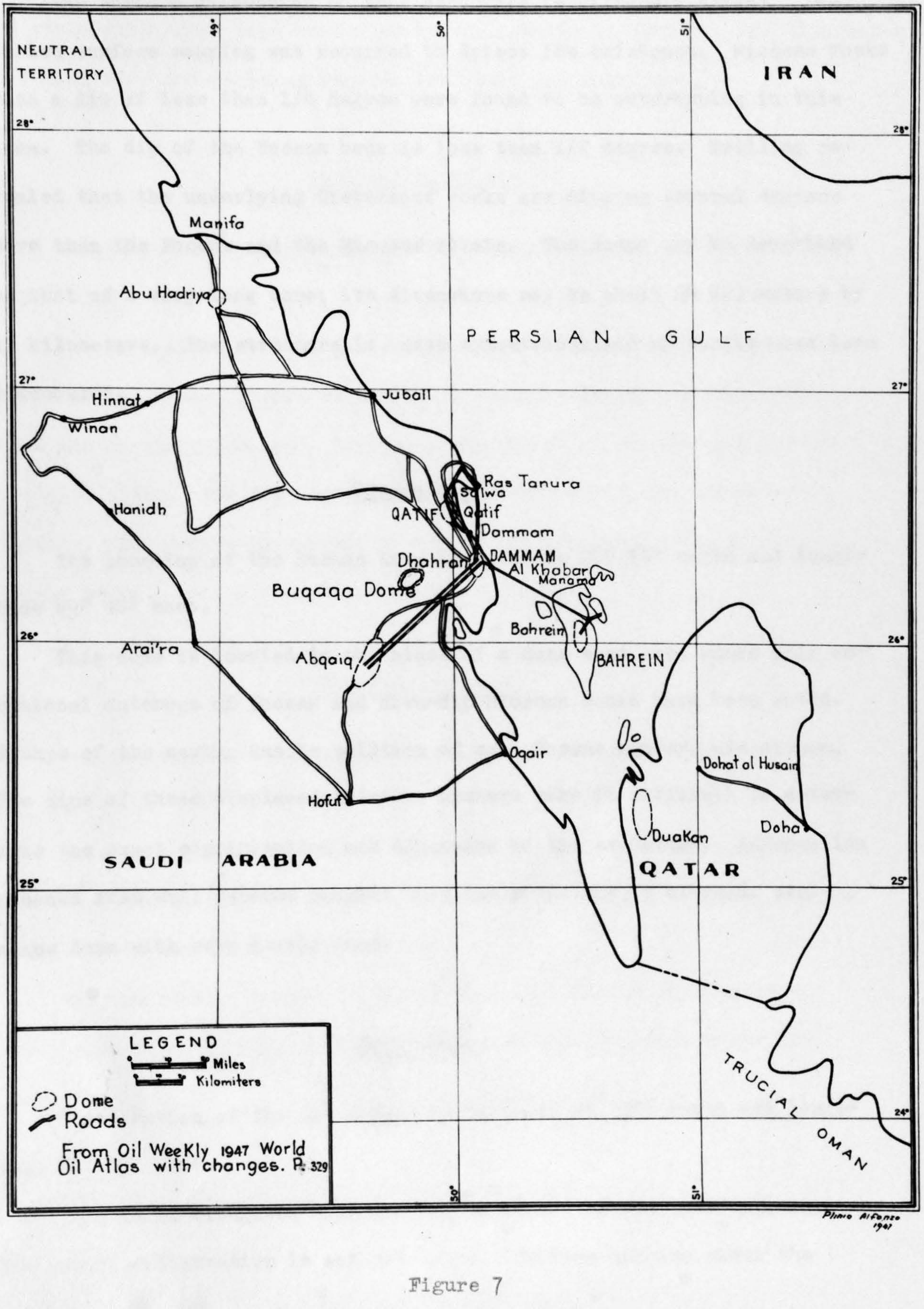

NEUTRAL TERRITORY
IRAN
49°
50°
51°
28°
27°
26°
25°
24°
Manifa
Abu Hadriya
PERSIAN GULF
Hinnat
Winan
Jubail
Ras Tanura
Salwa
QATIF
Qatif
Dammam
Hanidh
Dhahran
DAMMAM
Al Khobar
Manama
Buqaqa Dome
Bahrein
BAHREIN
Arai'ra
Abqaiq
Oqair
Dohat ol Husain
Hofuf
Doha
Duakan
SAUDI ARABIA
QATAR
TRUCIAL OMAN
LEGEND
Miles
Kilometers
Dome
Roads
From Oil WeeKly 1947 World Oil Atlas with changes. P. 329
Plinio Alfonzo 1947

Figure 7

The surface expression of this structure is extremely slight. Detailed surface mapping was required to detect its existence. Miocene rocks with a dip of less than 1/4 degree were found to be outcropping in this area. The dip of the Eocene beds is less than 1/2 degree. Drilling revealed that the underlying Cretaceous rocks are dipping several degrees more than the Eocene and the Miocene strata. The shape may be described as that of a very long dome; its dimensions may be about 24 kilometers by 12 kilometers. The structure is quite symmetrical and no faults have been discovered.

Bucaqa Dome

The location of the Bucaqa Dome is latitude 26° 14' north and longitude 49° 48' east.

This dome is located in the midst of a dune sand area where only occasional outcrops of Eocene and down-dip Miocene rocks have been noted. Slumps of the earth, due to solution of some Eocene member, are common. The dips of these displaced solution members make it difficult to determine the exact configuration and dimension of the structure. Information gleaned from well records suggest that the structure is a broad, oval-shape dome with very gentle dips.

Qatif Dome

The location of the Qatif Dome is latitude 26° 32' north and longitude 49° 59' east.

This is an elongated dome located just west of the Qatif gardens. Its exact configuration is not yet known. Surface mapping shows the structure to be an irregular one; numerous slumps caused by the solution of subsurface rocks have prevented its delineation. However, drilling has revealed some few facts as regards its shape and magnitude.

Ma'Aqala Structure

The location of this structure is latitude 26° 31' north and longitude 47° 20' east.

The Ma'Aqala structure is located on a barren, slightly dissected plateau-like area. Eocene rocks are exposed in the center of the structure and on the south end. Miocene rocks are found on its west, north and east sides. The dips of the central Eocene rocks are not determinable. The degree or amount of closure on the south side, if any, is not known.

Abu Hadriya Dome

The location of this dome is latitude 27° 22' north and longitude 49° 00' east.

This is a large, broad dome of about 16 kilometers in diameter. The existence of this structure was revealed by surface mapping, but the exact limits have not been determined.

Miocene rocks, exposed on the surface, consist of shaley sands, marls and chert. Definite surface dips have not been determined for these rocks.

STRUCTURAL FEATURE IN NORTH SAUDI ARABIA

El Jauf Structure

The location of this structure is latitude 28° 07' north and longitude 47° 56' east.

Low-dipping Miocene rocks, consisting of rather soft sandstones and sandy shales, are found on the surface of this structure. The presence of these low-angle dips suggested the probability of the presence of a major structural feature. A seismographic survey revealed decided dips on the flanks; these vary considerably, but, generally, they exceed 7 degrees.

A wild cat well drilled in this area reached a depth of about 3,658 meters. Oil showings were found at various horizons, but no oil zones of commercial importance were penetrated.

RESERVOIR CHARACTERISTICS OF THE OIL FIELDS IN THE PERSIAN GULF REGION OF SAUDI ARABIA[17]

Dammam Field

This field was the first to be discovered in Saudi Arabia. The first well was drilled with cable tools to the Bahrein zone of the lower Upper Cretaceous, reached at a depth of 3,203 feet. Several wells were subsequently drilled to this horizon with the hope of developing a supply of commercial importance, but the Bahrein zone which is fairly productive in Bahrein Island (35 miles from Dammam) proved to contain only a relatively small quantity of oil in the Dammam field.

Three of the wells which were drilled to the Bahrein zone are producing. Well No. 1 produces approximately 500 BPD of 50° API crude, with a gas-oil ratio of 860 cubic feet per barrel. The gas obtained from well No. 1 does not contain hydrogen sulphide, and therefore can be used for domestic purposes. Containing only small quantities of oil in Dammam field, as well as in Qatif and Abqaiq fields, the Bahrein zone reservoir was not adequately tested and little is known about its characteristics.

Failure to find large quantities of oil in the Bahrein zone in the first field drilled in Saudi Arabia led to deeper drilling in the same structure. Well No. 7 was drilled to 4,727 feet, with discovery of the Arab zone of upper Jurassic age, which is considered to be prolific in oil production. Dammam field now has more than thirty wells completed in the Arab zone. These wells, however, failed to give enough information

---

[17] Most of the material presented in this part of the thesis is furnished by the Arabian American Oil Company. (Reservoir characteristic of the oil fields in eastern Saudi Arabia.)

from which to obtain a clear idea about the structure of this reservoir. One or more faults were encountered in 16 of the wells completed in the Arab zone.

The Arab zone consists of four hydrocarbon-saturated limestone members, which are designated as the "A", "B", "C", and "D" members (See figure 8). The thickness of these members is 57', 25', 107' and 229', respectively. The porous limestone members are capped and separated from each other by an impermeable anhydrite. These members vary from extremely permeable and poorly cemented oolitic limestone to a dense, microcrystalline limestone. While "A", "B", and "D" members are quite productive, the "D" member, which contains 30 per cent of the total volume of the reservoir rocks is low in productivity.

All of the horizons contain oil of the same type. The gravity of the oil is approximately 35° API and each reservoir has a gas cap. This gas cap makes up about 15 per cent of the total volume of the hydrocarbon-saturated reservoir rock.

The oil-water contact for the various members is at the same sub-sea depth but the gas-oil contact varies because of the presence of the faults. The wells are spaced so as to produce a maximum of oil. They are located far from the gas-oil contacts so as to keep the producing gas-oil ratio almost the same as the ratio of the solution (gas-oil). These wells are properly located above the oil-water contact.

A packer is usually set above the lowest producing member in any well. The production from this lower member is obtained through the tubing, while the production from the other members is obtained through the casing-tubing annulus.

Acid is used to clean the gun perforations, but it causes the mud to flocculate. However, it also dissolves the limestone, causing the pores

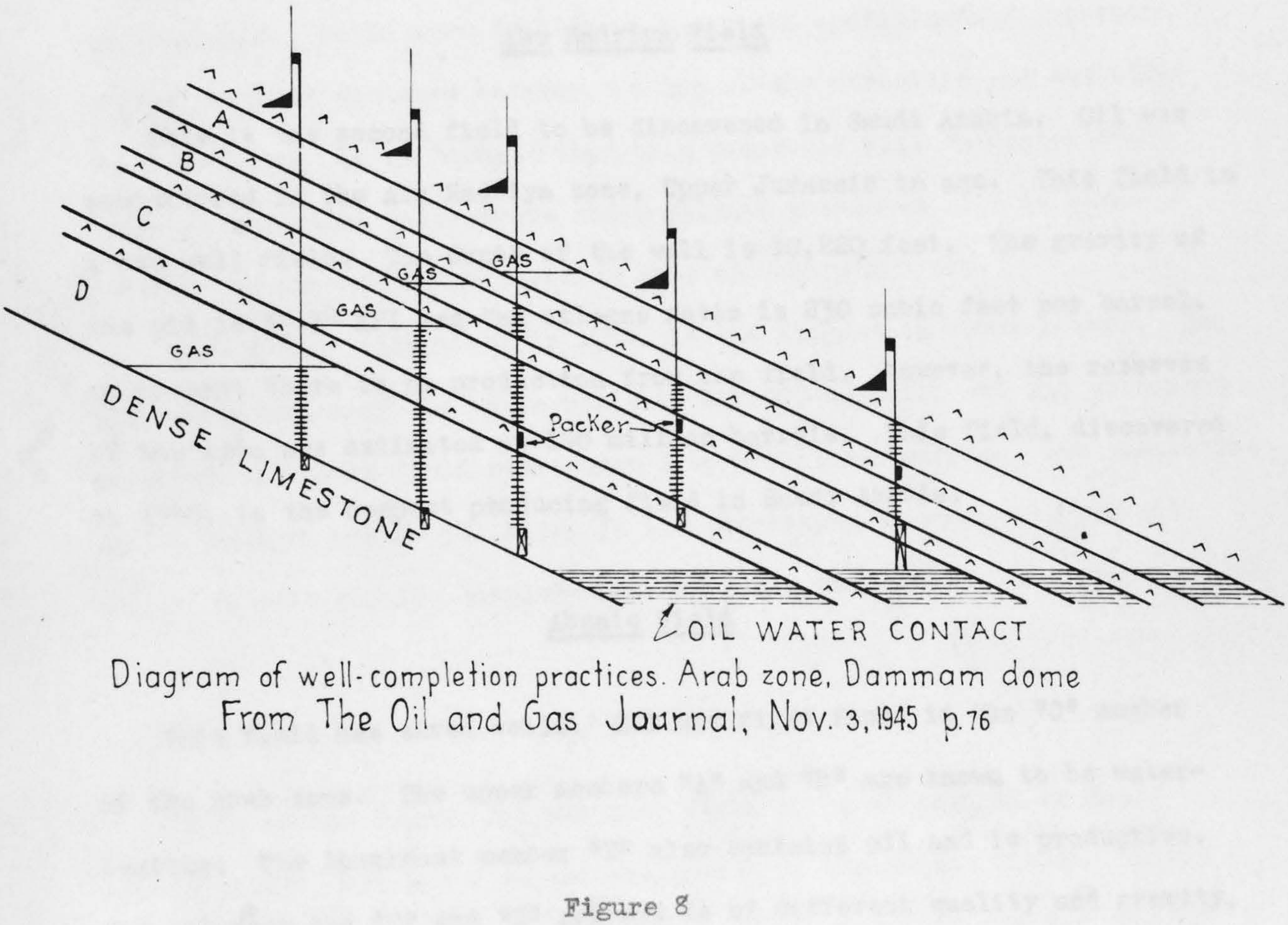


Diagram of well-completion practices. Arab zone, Dammam dome
From The Oil and Gas Journal, Nov. 3, 1945 p.76

Figure 8

to be freed of mud. Moreover, the acid washing alone sometimes improves the productivity of a well as much as 200 per cent.

This field was discovered in 1936; by 1946 its daily production was about 100,000 barrels and its cummulative production was 95,000,000. The proven area of the field is about 9,000 acres. The reserves of the Dammam field are estimated to be between 600 and 615 million barrels.[18]

Abu Hadriya Field

This is the second field to be discovered in Saudi Arabia. Oil was encountered in the Abu Hadriya zone, Upper Jurassic in age. This field is a one-well field. The depth of the well is 10,220 feet. The gravity of the oil is 35.7° API and the oil-gas ratio is 230 cubic feet per barrel. At present there is no production from the field. However, the reserves of the area are estimated at 140 million barrels. This field, discovered in 1940, is the deepest producing field in Saudi Arabia.

Abqaiq Field

This field has seven wells. Oil was first found in the "C" member of the Arab zone. The upper members "A" and "B" are known to be water-bearing. The lowermost member "D" also contains oil and is productive. The oil from the "C" and "D" members is of different quality and gravity, whereas the oil produced from these zone members in Dammam field was found to be alike. In this field, oil within the "C" member varies in gravity, for example, from 19° API gravity on the flank to 28° API gravity on the top of the structure. The oil reservoir, the "C" member, is about 80 feet

---

[18]1947 World Atlas. The Oil Weekly, p. 327.

TxU

thick in Abqaiq, but the permeable portion is only 35 feet thick. Member "D" is almost 232 feet thick and contains oil of 38° API gravity. The oil in the latter reservoir is undersaturated. The productivity indices of Abqaiq field wells exceed 150 BPD/PSI. Plans for producing this field include a limitation to 10,000 barrels per day for each well, thus keeping the gas-oil ratio to the desired minimum (about 900 cubic feet per barrel).

The "D" member reservoir is being developed according to a ring-spacing plan. Wells were drilled on a contour approximately one-third of the vertical distance between the top of the structure and the oil-water contact. It is thought that this reservoir will be exploited by means of a partial water-drive and a partial gas-drive. It is also planned to compensate the pressure by a secondary gas cap.

This field, discovered in 1940, is the largest in Saudi Arabia. The daily production of the seven wells is 112,000 barrels, and the estimated reserves of Abqaiq field range from 3 to 5 billion barrels. The cumulative output in 1946 was 24,801,193. It is interesting to note that the oil column in well No. 10, completed in 1946, was estimated to be 1,500 feet.

Qatif Field

This is the fourth and the last field to be discovered in Saudi Arabia (1945). It has a marked similarity to the Abqaiq field. Oil is produced from "C" and "D" members of the Arab zone, and the "A" and "B" members are wet. The gas-oil ratio of the "D" member crude is about 560 cubic feet per barrel.

The producing limestone members of Qatif field are denser and more crystalline than those of Abqaiq or Dammam wells. The "D" member here has the same thickness as that found in the other field, but its lower portion is impermeable.

This is also a one-well field. At the end of 1946 the well was flowing 2,675 barrels daily. The estimated reserve is thought to be about 50 million barrels. Its cummulative production through 1945-1946 was 1,140,966 barrels. The gravity of the oil is 29-28 degrees (API).

The total proved reserves of the four fields described, namely, Dammam, Abqaiq, Abu Hadriya and Qatif have been estimated at 3,715 million barrels and their present daily production is about 250,000 barrels.

BIBLIOGRAPHY

1. ....."General Discussion on the Cretaceous and Tertiary Stratigraphy on the Arabian Peninsula and Adjoining Areas," Arabian American Oil Company (Report).

2. ....."A Geological Reconnaissance of Northern Nejd Province, Northeastern Saudi Arabia," Arabian American Oil Company (Report).

3. ....."Structures in Saudi Arabia," Arabian American Oil Company.

4. ....."Measured Stratigraphic Section of the Upper Cretaceous, Eocene, Neogene, and Quaternary Along Wadi Aruma and Wadi Al Batin," Arabian American Oil Company.

5. ....."Reservoir Characteristics of the Oil Fields in Eastern Saudi Arabia," Arabian American Oil Company.

6. Dale, Nix. "Oil Development in Saudi Arabia," _The Mines Magazine_, November, 1946, p. 533.

7. De Golyer, E. "Oil Exploration in the Middle East," _The Mines Magazine_, November, 1946, p. 493.

8. Duce, J. T. "Foreign Oil Operations Marked by Uncertainties and Hidden Costs," _The Oil and Gas Journal_, vol. 46, No. 12, p. 160-161.

9. Lees, C. M. "The Geology of the Oil Fields Belt of Iran and Iraq," _The Science of Petroleum_, vol. 1, p. 140-148, Oxford University Press, 1938.

10. Miller, Robert P. "Drainage Lines in Bas-relief," _Journal of Geology_, vol. 45, No. 4, p. 432-438, 6 figs., May-June, 1937.

11. _Oil Weekly_, "1947 World Oil Atlas".

12. Picard, Leo. "On the Structure of the Arabian Peninsula," Hebrew University, Jerusalem, Geology Department, S.I.B. 3, 12 pp. (Engl. Hebrew Summ.), 4 figures (incl. sk. map) F '37, 1937.

This digital document does not include the vita page from the original.